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Characterization of Softmagnetic Thin Layers using Barkhausen Noise Microscopy

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ABSTRACT

Ferromagnetic materials are essential for data recording devices. For inductive or magnetoresistive (MR) sensors softmagnetic thin layer systems are used. Optimal performance of these layers requires homogeneous magnetic properties, especially a pronounced uniaxial magnetic anisotropy. Furthermore, microstructural imperfections and residual stresses influence the magnetic structure in the layer system.

Barkhausen Noise Microscopy enables the characterization of such thin layers. By cycling the magnetic hysteresis of ferromagnetic material electrical voltages (the Barkhausen noise) are induced in an inductive sensor. Miniaturization of the sensor and the scanning probe technique provides resolution down to few micrometers. Two materials were examined in terms of their structure, thickness, residual stresses and heat treatment condition: Sendust, used in inductive sensors and nanocrystalline NiFe, used in MR-sensors. In quality correlations to Barkhausen noise parameters were found. For representative sample a quantification of residual stress distribution could be established employing X-ray stress analysis.

INTRODUCTION

Currently there are several sophisticated methods available to image and characterize the magnetic structure of ferromagnetic thin layers. Especially Magnetic Force Microscopy MFM and Kerr-optical measurements are very popular. For dynamic magnetization processes ferromagnetic resonance spectroscopy or Brillouin scattering are frequently used. An important issue is the influence of mechanical properties, e.g. residual stress on the magnetic performance of the layer system. Residual stresses in such layers are due to non-optimized process conditions, undesired phase transitions or insufficient ductile adaptation to the substrate. They deteriorate the signal to noise ratio and thus the sensor sensitivity. Barkhausen Noise Microscopy provides the possibility to characterize mechanical and magnetic properties of softmagnetic layers both with high accuracy and lateral resolution.

EXPERIMENTAL DETAILS

By tracing the hysteresis curve of a ferromagnetic material, electrical impulses are induced in an electromagnetic inductive probe: the magnetic Barkhausen noise. Barkhausen events occur when domain wall movement has to overcome microstructural obstacles. Usually most noise activity can be measured in the vicinity of the coercivity H_C. The main parameters derived from the Barkhausen noise signal are the Barkhausen noise maximum M_{MAX} and the coercive field
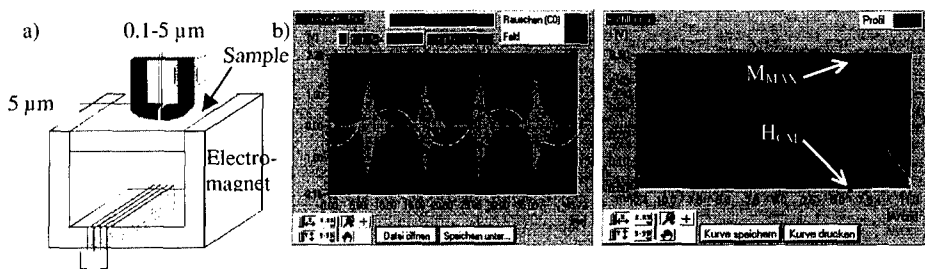
Figure 1. a) Schematic of miniaturized inductive sensor   b) Barkhausen noise signal

strength H_{CM}, which is the position of M_{MAX} within the magnetic field H (Fig. 1b) [1]. The Barkhausen Noise and Eddy Current Microscope (BEMI) enables the measurement of both Barkhausen noise and eddy currents [2]. A very efficient manipulation system precisely guides the miniaturized sensors to a positional accuracy of 1 μm across the surface to be tested. The sensors include ferrite cores with narrow air gaps (0.1 to 5 μm) that provide small exchange areas between sample and sensor and thus the possibility to map the Barkhausen noise with high lateral resolution down to 10 μm (Fig. 1a).

Two materials were examined: (i) Sendust (84.9 wt% Fe, 9.6 wt% Si, 5.5 wt% Al) used as layer material in inductive sensors, especially in data write units. Sendust achieves its best magnetic performance within a layer thickness range of 1-5 μm. However, it is necessary to anneal the sputtered material to obtain ordered intermetallic structures that provide the desired uniaxial magnetic anisotropy [3]; (ii) multi-layer systems of nanocrystalline NiFe used in magneto-resistive read sensors. This material can operate below a thickness of 20 nm providing the possibility of higher data density [3].

RESULTS

The magnetic properties of softmagnetic layers are significantly influenced by the layer thickness. This is exemplary shown for the coercivity in fig. 2a (H_C from hysteresis - and H_{CM} from Barkhausen noise measurements). The coercivity increases dramatically from 0.5 μm to 0.1 μm layer thickness.

The same thickness dependence can be observed for the residual stress states which can be explained with the high strain the first atomic layers of sputtered material has to endure due to the attachment to the substrate. The resulting stress can relax with increasing thickness. This mechanical property change will have an influence on the magnetic parameters (Figure 2 shows indirect the almost linear relation between stress and coercivity with respect to the film thickness), but basically the drastic change in coercivity is due to the change from Bloch wall - to Néel wall structures with decreasing thickness. Thus, BEMI measurements enable fast and easy determination of the threshold thickness for this phenomenon [4].

Using soft magnetic layers in read/write sensors requires homogeneous structural and magnetic properties, e.g. coercivity. Thus local variation of the H_{CM} parameter is an important

information for the use and optimization of magnetic layer systems. The H_{CM}-surface scan on a NiFe multi-layer system is shown in Fig. 3a. For comparison, Fig. 3b shows the H_C-values determined using a Kerr BH-Looper over the same area (5 x 5 measurement points). It is clearly apparent that there is good qualitative agreement between the results obtained [3,5,6].
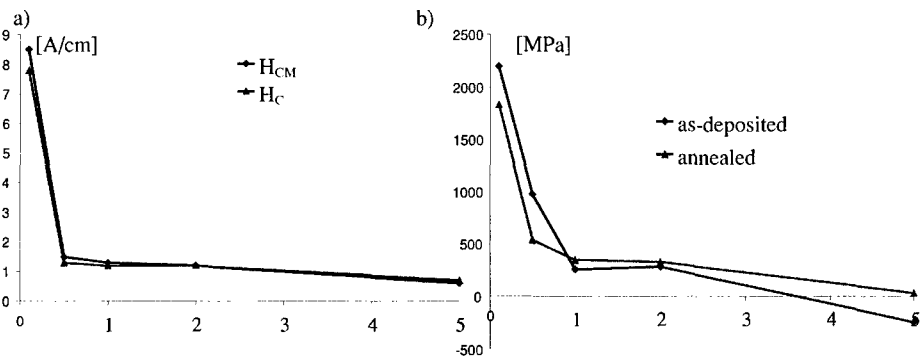

Figure 2. a) coercivity and b) residual stress as functions of Sendust layer thickness

Microstructure and texture of the magnetic layer can be significantly affected by changes in the growth condition of the column-like crystals. A possible method of manipulating this growth is applying an interface layer on the substrate prior to magnetic layer deposition. Coercivity, permeability and residual stresses of the magnetic layer can be varied over a broad range. Figure 4 shows SEM images of broken Sendust cross sections sputtered onto ceramic substrates. The ceramics were previously sputtered with either Cr- or SiO_2-interface layers. The images clearly show differences in the resulting crystalline structure of Sendust.
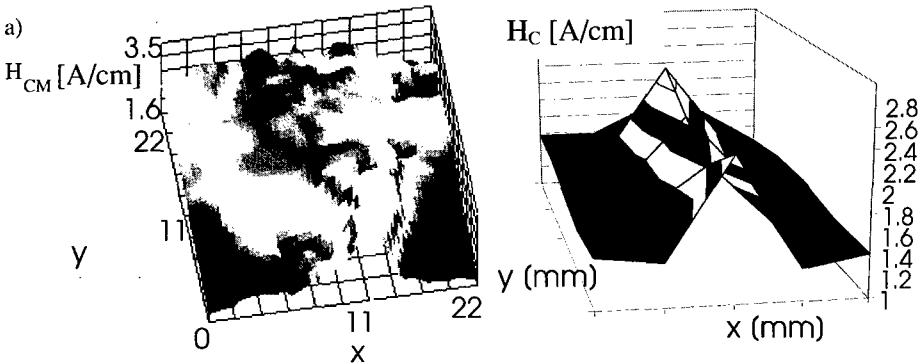

Figure 3. Mapping of coercivity (NiFe multi-layer system)
a) Barkhausen noise H_{CM}-scan   b) H_C-scan with Kerr BH-Looper

The clear dependence between Barkhausen profile and used interface layer is of great value for the processing of such magnetic layers. Figure 4 also shows the Barkhausen noise amplitude

as a function of time for 2 μm and 8 μm Sendust-layers sputtered either on Cr-layer or a SiO_2-layer. For the latter undesired high coercivity and low M_{MAX} can be observed. Specific individual structural properties of the coatings such as their microstructural condition (phase proportion, grain size) and residual stress apparently affect the domain wall movement in a very significant and characteristic way. The noise profile permits controlling the growth conditions of soft magnetic layers to be during manufacturing [3,5,6].
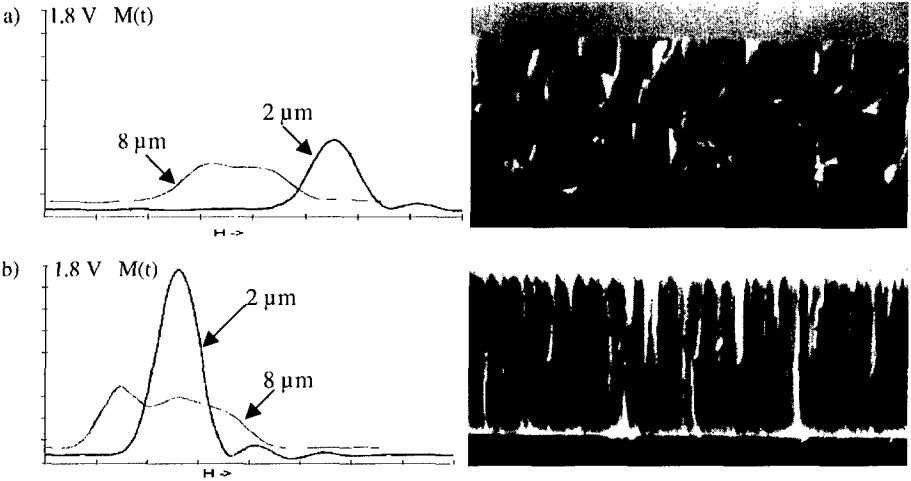

Figure 4. Barkhausen noise over time and cross section SEM images for Sendust-layers of 2 μm and 8 μm   a) with SiO_2 interface layer   b) with Cr interface layer

The effect of tensile and compressive stresses on the Barkhausen amplitude is a result of the partial ordering processes taking place within the magnetic structure. The coercive field strength (magnetic hardness) generally increases with increasing mechanical hardness. For quantitative nondestructive hardness or residual stress measurements, the magnetic test parameters must be calibrated with the help of mechanical hardness or stress measurements [1].

Using X-ray diffraction, it was possible to make a number of residual stress measurements on a single specimen (diameter of the X-ray beam: approx. 100 μm). Figure 5 shows a M_{MAX}- scan compared to the X-ray scan of the exact same area (2x2 mm^2) on a annealed Sendust sample (layer thickness: 2 μm). The two images show almost identical structures. In addition, both the residual stress values and the M_{MAX}-values within this area have comparably high gradients (310 – 396 MPa and 2.26 – 3.84 V). Thus, the BEMI enables fast and highly resolved qualitative (and with proper calibration) quantitative determination of the residual stress distribution across a thin soft magnetic layer [3,5,6,7].
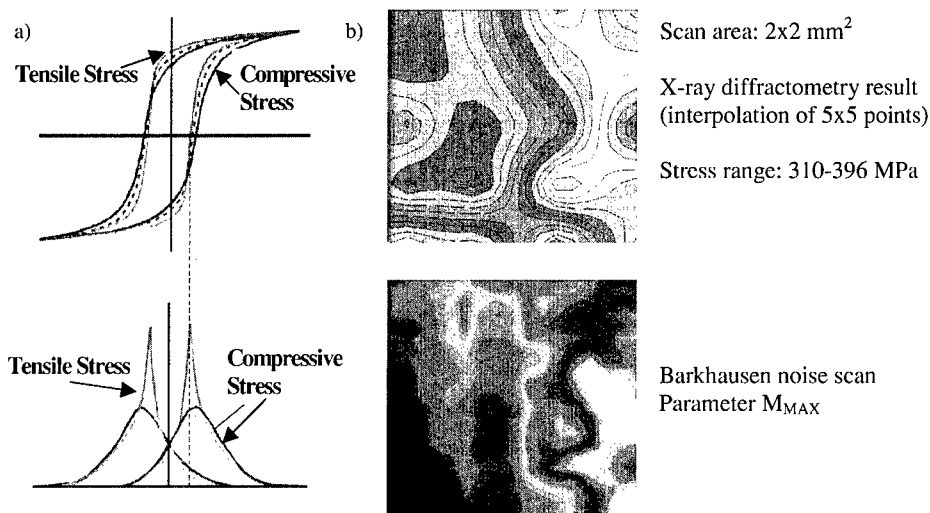
Figure 5. a) Stress influence on magnetic properties
b) Mapping of M_{MAX} compared to X-ray stress analysis on 5 µm thick Sendust

SUMMARY

Barkhausen Noise Microscopy (BEMI) provides high potential for improving the development and manufacturing of new magnetic materials. It can be used to optimize the processing parameters used during processing of thin ferromagnetic layers. The efficiency of Barkhausen noise microscopy was demonstrated on a series of thin softmagnetic materials.

The BEMI could be used to provide important information about the microstructure or the magnetic hardness of these materials. It was possible to distinguish between Bloch- and Néel wall domain structures by evaluating the coercivity of the respective samples. Using the BEMI a quick and highly localized qualitative, and by calibrating the results with by X-ray diffraction quantitative, determination of the residual stress present in Sendust samples can be obtained. Investigations carried out on Sendust-coatings with different coating structures show that the BEMI allows the examination of structural differences resulting from the use of different types of intermediate layers, such as SiO_2 and Cr.

ACKNOWLEDGEMENTS

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